A Foundation for Continuing Space Achievement: The NASA Cartography Program and the PDS

A Response to NASA RFI NNH15ZDA012L (Preparation for the Development of a Community-based Roadmap for the Planetary Data System and associated organizations) by the Steering Committee of the Mapping and Planetary Spatial Infrastructure Team (MAPSIT):

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Executive Summary: The NASA planetary cartography program provides a critical enabling foundation for worldwide planetary science research by providing the geodetically controlled data sets, enabling software tools, content delivery systems, and the geospatial training the community needs to do planetary science research. In this context, continued support of NASA planetary cartography strategic planning and the Cartography program itself is vital to ensure a continuing leadership role for American planetary science. To maximize the return on investment over the next five years, the Cartography program should continue to provide software support to make it as easy as possible to work with data from the PDS, while continuing to produce the valuable new cartographically controlled, highly usable data products required for science research. Active and inclusive community-oriented feedback and long-range planning for the cartography portfolio is required to ensure that data products and software tool development actually reflect the strategic needs of the planetary science community.

Introduction: Cartography signifies the science and practice of placing information in a standards-compliant, community-recognized spatial framework. The goal of planetary cartography is to enable any conceivable science investigation with returned planetary mission data, now or in the future. When properly executed, these standards-compliant cartographic products are a resource that continue to produce scientific benefits for decades after the flight operations of a planetary mission is concluded. Thus, planetary cartography is the critical enabler for science investigation and human exploration planning for all planetary bodies. However, cartographic products require substantial efforts in time, research, foundational supporting infrastructure to properly execute. Given the current emphasis within PDS for development of "usable" data products, it makes sense that there should be coordination between the NASA-funded Cartography program and the PDS toward the development of such products. Inclusive, community-based strategic planning for planetary cartography is essential for successful planetary science research, particularly as to what should be done first given current resources, and the PDS community must be part of this planning. *Here we provide a brief history behind the NASA cartography program, summarize looming issues in present-day strategic cartography planning, and highlight areas where strategic investments in foundational infrastructure are becoming more important.*

In the remainder of this response we will address not just one but several of the topics under which the RFI requests input. In particular, we highlight the importance of the Cartography program, and the MAPSIT's plans to help with overall planetary cartography planning. Such an effort should for example address the RFI issues of (RFI no. 1) needed tools, resources, workflows, and tutorials; (2) ways to help data providers create optimal cartographic products that meet PDS and other requirements; (5) how cartographic products can be tied or integrated with Minor Planets Center data; (6) the role of all components of NASA, including the PDS, in planning for, prioritizing, encouraging, and funding cartographic ("higher order") data products and assuring that appropriate standards are followed, and that precision and accuracy and overall quality if such products are well quantified; and (7) which new techniques need to be developed to handle both past datasets and current and future massive datasets, including for use in improving search and access capabilities via the PDS and other avenues.

Background: Historically, planetary cartography has involved broad segments of the community. During the Apollo era, multiple organizations helped to plan and carry out cartographic tasks, including the United States Geological Survey (USGS), NASA Johnson Space Center, the National Geodetic Survey, the Defense Mapping Agency, RAND, members of academia, and others. Table 1 lists the various groups that have historically been established to coordinate these efforts, disseminate information to the broader community, and advise NASA on cartographic matters [1-4].

Table 1. List of Planetary Cartography Advisory Bodies

Start Date	Name
1974	Lunar and Planetary Cartography Committee
1977	Lunar and Planetary Photography and Cartography Committee
1979	Planetary Cartography Working Group
1994	Planetary Cartography and Geologic Mapping Working Group
2015	Mapping and Planetary Spatial Infrastructure Team

The former Planetary Cartography and Geologic Mapping Working Group (PCGMWG) included broad representation from the planetary science community, such as a dedicated Geologic Mapping subcommittee. From 1994 to 2012, the PCGMWG served as NASA's principal community-based body and made cartography recommendations to NASA, including submitting a white paper on cartography [5] to the NRC Decadal Survey. The PCGMWG ceased making cartography recommendations in 2012, but continued to execute an External Review of the NASA Planetary Cartography program until 2015. With the end of the Planetary Geology and Geophysics program, the PCGMWG was disbanded in 2015. The lack of a principal community-based advisory body for cartographic matters meant there was a critical gap in long-range planning for cartographic product, particularly prioritizing new data products and providing the necessary strategic vision for cartographic input for current and projected future missions.

Situation: Historically, the Cartography program has produced new software tools, new higher-order data products, new planetary geologic maps, and updated planetary nomenclature databases for the community. Advances in the past decade have made it easier than ever before

for interested groups and community agents to produce cartographic products, including: formal geologic maps, figures in papers, and global datasets from for numerous Solar System bodies. ***Many of these advances were directly enabled by the NASA Cartography program***. The Cartography program has supported much of the development and maintenance of the USGS Integrated Software for Imagers and Spectrometers (ISIS), a freely available software tool used by the Astrogeology Science Center, mission teams, and individual researchers. However, at the same time, large volume of data being returned from legacy (e.g., Mars Global Surveyor) and current flight missions (e.g., Mars Reconnaissance Orbiter) has rapidly outstripped the capability of individual scientists to process, store, and geodetically control at anything other than the local scale.

For example, preliminary LRO data has been used to craft the Lunar North Polar Mosaic (LNPM), consisting of 680 gigapixels of valid image data covering a region of the Moon (2.54 million km², 0.98 million miles²) slightly larger than the combined area of Alaska (1.72 million km²) and Texas (0.70 million km²) at a resolution of 2 meters per pixel. The LNPM is the first of a new generation of very useful and important science products, but the ability to control it and register all of the images at the sub-pixel level does not presently exist. In the future, other new products like the LNPM that require similarly large computer clusters to process are going to become even more commonly used for science investigations and will require subpixel registration at known levels of absolute accuracy. In fact, any new geodetically controlled data products, such as the global THEMIS mosaics currently being supported by the Cartography program, can take significant investments in time and resources to bring to fruition. Improvement of theory, algorithms, and software tools could greatly lower the costs involved and result in superior products and better science outcomes. Prioritizing the development of software tools and data products for the community requires continuous and vigorous inclusive community feedback to help ensure that wise investments are being made.

MAPSIT: To address the urgent need for strategic planning for planetary cartography, the NASA Planetary Science Subcommittee recommended the formation of a dedicated community group to help coordinate NASA strategic planning needs for planetary cartography in September 2014. To this end, NASA and the USGS have worked together to establish the Mapping and Planetary Spatial Infrastructure Team (MAPSIT) under the terms of the most recent USGS-NASA Interagency agreement for the Cartography program. MAPSIT assumes some of the historic roles of the PCGMWG and includes some of its former members for continuity. The MAPSIT Steering Committee includes membership from the planetary science, geologic mapping, software development, and human exploration communities.

MAPSIT's mission is nothing less than *to ensure that planetary geospatial information and tools are readily available for any conceivable investigation, now or in the future.* In this role, MAPSIT serves several functions:

- Provide community findings concerning the scientific rationale, objectives, technology, and long-range strategic priorities for geologic mapping, geospatial software development, and cartographic programs to NASA and the USGS;
- Assist with developing cartographic, planetary nomenclature, and geologic mapping standards for present and future flight missions and research activities;

- Help define community needs for critical research and planetary mission infrastructure, particularly software tools and content delivery systems;
- Provide findings on the accuracy and precision required for cartographic technologies and products; and
- Coordinate and promote the registration of datasets from international missions with those from US missions to optimize their utility.

MAPSIT will help enable development of the broad spectrum of geospatial data products and programmatic capabilities required to effectively execute robotic precursor and human exploration of the Solar System. These include (but are not limited to the rigorous scientific analysis of planetary surfaces, the identification of safe landing sites, the downselection of sample acquisition locations, hazard assessment, and the geospatial characterization of in-situ resources [e.g., 6-8].

Issues: To maximize efficiency and control costs, there are numerous high priority issues that MAPSIT and the larger planetary science community must address in the years to come, including:

- How should the exciting new influx of planetary mission data sets (e.g., the Mars Reconnaissance Orbiter, the Lunar Reconnaissance Orbiter, MESSENGER) be geodetically controlled and integrated to enable science and operation of current and future missions?
- What should the prioritization be of the global, regional and local topographic models that could be created from multiple available data sets?
- What requirements (e.g., archival, geodetic) should be developed for missions to follow with respect to cartographic needs during the formulation and definition stages to mitigate subsequent cost-growth?
- How can NASA's Research and Analysis programs support development of enabling software tools, mapping procedures, and critical content delivery infrastructure for new and complex products?
- How can cartographic products be used to enable and facilitate future human exploration and in-situ resource utilization? [9]
- When and how should mapping tools be developed and how should they be tested for accuracy and usability?

An example of the kind of in-depth assessment MAPSIT can help facilitate is addressing the needs for new or improved tools to handle the vast data volumes of current and planned missions. Examples include (1) faster and more robust matching between disparate data types, enabling new types of data fusion; (2) ability to simultaneously adjust data from different platforms (e.g., orbital, descent, lander, and rover) data types (e.g., images, radar, and altimetry), and bodies (e.g., planets, planetary satellites, dwarf planets and large asteroids, irregular asteroids and comets); and (3) new tools to combine different methods for generating topographic information, especially combining LIDAR and image-based techniques. In the current budget environment, it is impossible to develop all the desired tools concurrently, and so the community must prioritize desirable capabilities that can be enabled by near-term investments in software tool development.

A New Strategic Plan: MAPSIT has begun to synthesize a new Planetary Geospatial Strategic Plan (PGSP) in 2016. To build the PGSP, MAPSIT will solicit broad stakeholder input through community surveys and town hall meetings in order to prioritize the needed data products and infrastructural developments, following a process much like the Lunar Exploration Analysis Group's Lunar Exploration Roadmap [9] and the 2015 Small Bodies Assessment Group Goals Document [10]. It is envisioned that the MAPSIT Strategic Plan will be a "Living Document" that evolves over time as milestones are met and the state of the art advances. MAPSIT will ensure that the PDS is involved in these discussions so that interoperability with PDS data products and services is considered and supported where possible.

Conclusions: The Cartography program has played a key foundational role in the success of NASA's planetary missions and associated research activities for decades. While many issues relating to cartography and software tools face our community, the Cartography program will remain the vanguard for enabling our community to achieve its goals. Effective strategic planning for the Cartography program, beginning with the MAPSIT Planetary Cartography Strategic Plan, is an essential part of this process.

References:

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